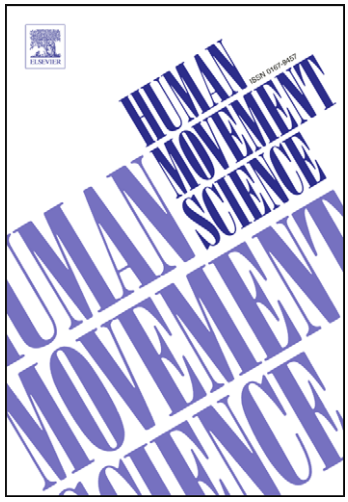
Anticipation of Tennis Shot Direction from Whole-body Movement: The role of movement amplitude and dynamics

N.J. Smeeton, R. Huys



Anticipation of Tennis Shot Direction from Whole-body Movement: The role of movement amplitude and dynamics

N.J. Smeeton, R. Huys

PII: S0167-9457(10)00112-0
DOI: 10.1016/j.humov.2010.07.012
Reference: HUMOV 1274

To appear in: *Human Movement Science*

Please cite this article as: Smeeton, N.J., Huys, R., Anticipation of Tennis Shot Direction from Whole-body Movement: The role of movement amplitude and dynamics, *Human Movement Science* (2010), doi: 10.1016/j.humov.2010.07.012

Anticipation of Tennis Shot Direction from Whole-body Movement: The role of movement amplitude and dynamics.

Smeeton, N.J. [1] and Huys, R. [2]

[1] University of Brighton, Chelsea School, UK

[2] Université de la Méditerranée & CNRS, France

Running heading: Movement Amplitude and Dynamics in Anticipation

Corresponding author:

Nicholas J. Smeeton, PhD

Chelsea School

University of Brighton

Denton Road

Eastbourne, East Sussex, BN20 7SR (UK)

Phone: +44 (0)1273 643714

Fax: +44 (0)1273 643704

email: n.j.smeeton@brighton.ac.uk

Abstract

While recent studies indicate that observers are able to use dynamic information to anticipate whole-body actions like tennis shots, it is less clear whether the action's amplitude may also allow for anticipation. We therefore examined the role of movement dynamics and amplitude for the anticipation of tennis shot direction. In a previous study, movement dynamics and amplitude were separated from the kinematics of tennis players' forehand groundstrokes. In the present study, these were manipulated and tennis shots were simulated. Three conditions were created in which shot direction differences were either preserved or removed: Dynamics-Present-Amplitude-Present (D^PA^P), Dynamics-Present-Amplitude-Absent (D^PA^A), and Dynamics-Absent-Amplitude-Present (D^AA^P). Nineteen low-skill and fifteen intermediate-skill tennis players watched the simulated shots and predicted shot direction from movements prior to ball-racket contact only. Percent of correctly predicted shots per condition was measured. On average, both groups' performance was superior when the dynamics were present (the D^PA^P and D^PA^A conditions) compared to when it was absent (the D^AA^P condition). However, the intermediate-skill players performed above chance independent of amplitude differences in shots (i.e., both the D^PA^P and D^PA^A conditions), whereas the low-skill group only performed above chance when amplitude differences were absent (the D^PA^A condition). These results suggest that the movement's dynamics but not their amplitude provides information from which tennis-shot direction can be anticipated. Furthermore, the successful extraction of dynamical information may be hampered by amplitude differences in a skill dependent manner.

Key Words: Expert-novice, biological motion perception, PCA, sport, prediction, advance-cue

PsycINFO classification: **2330** Motor Processes; **2323** Visual Perception; **3720** Sports

Running head: Movement Amplitude and Dynamics in Anticipation

1. Introduction

Researchers investigating biological motion perception have tried to identify the optical information that allows for the successful detection and identification of agents and the anticipation of their actions. While various candidates have been suggested in terms of motion-based and form-based information (see Blake & Shiffrar, 2006, for a review), it is now generally thought that the relevant information underlying actor and action identification is contained in the motion patterns as opposed to anatomical or physical features providing such information (cf. Johansson, 1976; Runeson & Frykholm, 1983; Troje, 2002; Westhoff & Troje, 2007). The information conveying an action's outcome, as in anticipation, has been less thoroughly explored.

Ward, Williams, and Bennett (2002) examined whether the motion patterns of tennis shots contain the information about the outcome of an agent's action (see also Abernethy, Gill, Parks, & Packer, 2001). Using an expert-novice design, they asked participants to indicate shot directions from viewing video and point light display (PLD) versions of tennis groundstrokes. Results showed that the expert tennis players' superior ability to anticipate shot direction over the novice players as normally observed with video displays was maintained in the PLD display conditions, although performance on average worsened in the PLD condition relative to the video condition. The maintenance of the skill-based difference was interpreted as evidence that the motion patterns contain the information allowing observers to anticipate the action's outcome (see also Shim, Carlton, Chow, & Chae, 2005). Their method, however, did not allow for the identification of what motion-based visual information enables anticipation of an agent's actions.

This latter issue was recently investigated by Huys and colleagues (Huys, Smeeton, Hodges, Beek, & Williams, 2008; Huys, Cañal-Bruland, Hagemann, Beek, Smeeton, & Williams, 2009). These authors departed from the perspective founded in synergetics that high-dimensional (self-organizing) systems can often be effectively approximated by a limited number of so-called macroscopic structures (or order parameters; cf. Haken, 1996; Kelso, 1995). As these (dynamical) structures effectively capture the system's state, they may be said to be informational. In that regard, (deterministic, time-continuous, and autonomous) dynamical systems can be unambiguously described through their flow in phase space (cf. Strogatz, 1994). In other words, phase flows capture the causation underlying the time evolution of such dynamical systems. Of late, the (topological) structure in phase flows has been used as a conceptual tool for the categorization of (discrete and rhythmic) movements (Huys, Studenka, Rheaume, Zelaznik, & Jirsa, 2008; Jirsa & Kelso, 2005). Phase flow patterns, however, may also underlie the perceptual recognition of distinct motor processes (Perdikis & Jirsa, 2010; see also Muchisky & Bingham, 2002). For the purposes of visual identification of human movement, visual recognition of biological motion may proceed through the extraction of these (macroscopic) dynamical structures (Haken, 1996, 2000, 2004). A powerful and statistically unbiased method to extract the low-dimensional dynamics in high-dimensional movement patterns is principal component analysis (PCA; see Daffertshofer, Lamoth, Meijer, and Beek, (2004) for a tutorial). PCA is based on the covariance among the time evolutions of all the system's components, and separates (orthogonal) variances in a dataset relative to their overall contribution to the data's entire variance. This feature was exploited by Huys et al. (2008) when they attempted to find empirical evidence that low-dimensional dynamical structures contain the visual information underpinning

anticipation. To identify kinematic differences in shots delivered to different directions, whole-body kinematics of six right-handed tennis players performing forehand groundstrokes to two directions (leftward and rightward shots) and two distances (short and deep) were recorded. The corresponding time series of all conditions and participants were subjected to PCA. Before running PCA, each time series was divided by its standard deviation in order to eliminate differences in motion amplitudes across the body and solely focus on the dynamics. (Without this procedure trajectories with larger amplitudes would have a heavier weighing in the analysis than those with smaller amplitudes.) Note that, by using this procedure, the PCA separates trial-to-trial variations that typically do not (or hardly) co-vary and thus cannot be reliably used for anticipation from temporal evolutions that are present across trials and even players. The corresponding later variance may thus be said to be statistically invariant. Huys et al. found that a few modes, or dynamic structures, captured approximately 90% of the total variance, and that tennis shots to different directions were distinguishable in terms of the degree of contribution from the various anatomical landmarks to these modes. Distance differences were few and far between. To test whether human observers can anticipate shot direction based on these modes, stick figure simulations were created based on several combinations of the dominant modes. In order to obtain stick figures with motion patterns with "real" 3D movements, the modes were multiplied by the time series' standard deviation (following the normalization division prior to PCA) and the mean was added (back). Results from experiments using these simulations showed that the presence of a few dynamic structures allowed for undisrupted anticipation of shot direction. The authors concluded that skilful anticipation results from being able to extract this (low-dimensional) information from high-dimensional displays.

The tennis shots analyzed by Huys et al. (2008), however, were not only distinguished by different dynamics. In fact, the statistical analysis of the time series' standard deviation, which provides a measure of the movements' excursion (or the scaling of the trajectory), and to which we here refer to as movement amplitude, revealed significantly larger movement amplitudes across the whole body for shots directed to the right-hand-side of the opponent's court compared to shots directed to the left-hand-side of the court[1]. The potential utilization of these amplitude differences for anticipation of shot direction was not examined, however.

Elsewhere in the literature movement exaggeration has, to some extent, thought to provide visual information to identify tennis serve style as well as emotion from facial expressions and pedestrians by drivers (e.g., Pollick, Fidopiastis, & Branden, 2001, Atkinson, Dittrich, Gemmel, & Young, 2004, Balk, Tyrrell, Brooks, & Carpenter, 2008). Pollick et al. spatially exaggerated tennis serves by changing the movements' spatial distances between the serve style average and the grand average for three different styles. After 360 trials of perceptual training, they found that exaggeration improved recreational players' abilities to categorize flat serves although no improvement was found for slice or topspin serves. It is possible that the improved recognition of the flat serve style found by Pollick and colleagues occurred because of the changes in amplitude during the process of exaggerating the serves. However, the exaggeration may also have affected the movement dynamics, and because amplitude was not isolated from the dynamics, it is not possible determine their respective roles.

We investigated if movement amplitude, next to the dynamics, facilitates anticipation of tennis passing shot direction, and whether tennis skill level mediates such potential effect. We thereto simulated whole-body movements of tennis passing shots to two directions and manipulated potential direction-specific information held

in the dynamic structures and the movement amplitude. Based on the theoretical perspective outlined above, we expected that, in isolation, the information pertaining to the dynamic structures but not that pertaining to amplitude differences would allow for anticipating shot direction (Huys et al., 2008). In addition, we anticipated that combining dynamical information with movement amplitude may further facilitate anticipation in a skill-dependent manner (Pollick et al., 2001), but expect that if so, the effect would be small.

2. Method

2.1. Participants

Nineteen low-skill participants (mean age = 22.2 years, *SD* = 3.4) who had not received professional tennis coaching (10 male, 9 female) and fifteen intermediate-skill participants (mean age = 22.7 years, *SD* = 3.5) who had received a mean average of 6.4 years (*SD* = 4.1) of tennis coaching (8 male, 7 female) consented to participate. Prior to participation in this experiment, informed consent was obtained and the research was conducted in accordance with the ethical guidelines of the University of Brighton.

2.2. Apparatus and stimulus production

Stick-figure simulations of tennis shots were created using Matlab (Matlab 6.5, the Mathworks). Each simulation was saved in Audio Video Interleave (AVI) format with a frame rate of 30 Hz. The simulations were based on the data collected by Huys et al. (2008). In brief, six right handed players performed tennis strokes to different directions while three-dimensional displacement data were captured from spherical retroflective markers that were attached to 18 anatomical landmarks and the

tennis racket (left and right shoulder, elbow, wrist, hip, knee, ankle, toe, top, bottom, left, and right side of the racket face; see Huys et al. (2008) for details). Each of the resulting time series were re-sampled to the mean length of all time-series, mean subtracted, normalized by dividing it by its standard deviation, and combined into an N-dimensional state vector $\boldsymbol{q}(t)$ (N = 6 [participants] × 4 [conditions] × 4 [trials] × 54 [time-series] = 5184; with $t = t_{start} \ldots t_{ball\ contact}$). Next, $\boldsymbol{q}(t)$ was subjected to PCA, and the projections $\xi_k(t)$ (i.e., the time evolutions corresponding to mode k) were computed.

Here, 54 modes (capturing more than 99% of all the variance in the entire data set) were used for all the simulations, and shot-distance differences in eigenvector coefficients were averaged out per mode (see also Experiment 3 from Huys et al. (2008) and Huys et al. (2009)). To generate new data, $\boldsymbol{u}(t)$, for the simulations we computed the product of the projections $\xi_k(t)$ and the eigenvectors of mode 1 to 54, resulting in a 54-dimensional vector $\boldsymbol{u}(t)$ representing the dynamics corresponding to the 18 marker locations in 3 Cartesian directions. Data in "real-world" coordinates were then obtained via multiplication of each (marker's) time-series $u_i(t)$ with a realistic standard deviation (for instance, the corresponding marker-specific mean standard deviation; see below) and addition of a realistic mean.

In this experiment, when creating simulations for the Dynamics-Present-Amplitude-Present (D^PA^P) condition, the shot differences present in the eigenvectors as well as in the standard deviations were preserved for each shot direction. The means and standard deviations of time series from two participants (one male, one female) were selected that were closest to the averages of the time-series' standard deviations and their own. In addition, simulations were made that contained the shot-direction differences in the dynamics whilst shot-direction differences in amplitude

was eliminated by averaging the standard deviations of the time series across shots to the left and right direction, to which we refer as the Dynamics-Present-Amplitude-Absent (D^PA^A) condition. Finally, simulations were created in which the shot-direction differences in the dynamics were eliminated by averaging the eigenvector coefficients across left and right shot directions whilst amplitude differences were maintained (similar to the D^PA^P condition). We refer to this condition as the Dynamics-Absent-Amplitude-Present (D^AA^P) condition. The frame rate for all the simulations was 30 Hz. We thereto re-sampled the time-series of the shots to a multiple of 30, while minimizing changes in the number of samples

The AVI files were imported into Adobe Premier 6.0 (Washington, US) on a notebook computer (Sony, Tokyo, Japan) with a 15-inch screen. From these files trials were created by editing a 1-s presentation of a white background with a centrally placed black dot, followed by a 1-s presentation of the white background alone before the AVI file. Finally, a white background lasting 3 s was placed after the AVI file. A total of 60 trials were randomized across conditions, 20 trials (10 left side of the court, 10 right side of the court) per condition. A practice test tape of 12 trials was constructed in a similar manner in which example shots were presented in a blocked order (a left and right shot from the D^PA^P, D^PA^A and D^AA^P conditions).

2.3. Procedure

Participants sat at about a distance of 0.5 m from the laptop which was used to display the experimental trials. Before they viewed the experimental trials, participants were told to imagine themselves in the centre of a tennis court in the middle of the baseline and that they would be shown tennis shots directed to either their left or right. The opponent was located at the same position as the participant but

on the other side of the court. Participants were also told that the simulated shots were in the form of a stick figure (without a head), and that the clips lasted up to the moment of ball-racket contact but that no ball would be presented. They were then notified of what each trial consisted of. Participants were asked to quickly and accurately indicate the direction of each shot (left or right) after the simulation had finished via a pen and paper response[2]. This instruction was important because experimentally we wanted all participants to see all the information but we did not want participants to make decisions based on the memory of the stimuli just viewed. Before the experimental trials were shown, participants viewed the practice trials. Shot direction was indicated before their presentation. The experiment lasted about 10 minutes.

2.4. Data Analysis

Before inferential statistics were calculated, percentage of correct answers (c) for each experimental condition were transformed this number using Bartlett's modified arcsine transformation according to $p' = (360/2\pi)\arcsin\left(\sqrt{(c+3/8)/(n+3/4)}\right)$, with n being the number of trials (Bartlett, 1937, in Zar, 1996). The transformed scores were then subjected to a mixed design ANOVA with Information Source as the within-participant factor (dynamics, amplitude) and skill as between-participant factor (low-skill, intermediate-skill). Effect sizes were estimated using partial Eta Squared (η_p^2). One sample t-tests were used to examine performance above chance level. Untransformed means and standard deviations that were calculated from the original data are graphed and reported in the text.

3. Results

Examining the relative difference between the skill groups and potential "informers" (i.e., the motion's dynamics and amplitudes), a two-way mixed design ANOVA revealed that intermediate-skill tennis players predicted shot direction more accurately than low-skill players, $F(1, 32) = 6.32$, $p = .017$, $\eta_p^2 = .165$ (intermediate-skill mean = 62.0%, *SD* = 17.5, low-skill mean = 52.8% *SD* = 17.8). In addition, there was a main effect of Information, $F(2, 64) = 3.33$, $p = .042$, $\eta_p^2 = .094$ (see Fig. 1). Follow up analysis, via repeated contrasts, indicated that shot prediction accuracy in the both the D^PA^P (mean = 59.7% *SD* = 20.0) and D^PA^A (mean = 60.0% *SD* = 16.7) conditions were greater than the D^AA^P (mean = 50.8% *SD* = 16.5) condition. No significant interaction effect was found.

To examine which information potentially enabled anticipation, performance relative to chance level was compared for each skill group (see Fig. 2). One sample *t*-tests showed that performance in the D^PA^A condition only was significantly above chance level in the low-skill group (Mean = 56.8%, *SD* = 16.7), whereas the intermediate-skill group demonstrated above chance level performance in the D^PA^P and D^PA^A condition (Mean = 69.3% *SD* = 16.7 and Mean = 64.0% *SD* = 16.3 respectively) but not in the D^AA^P condition.

Please insert Figs. 1 and 2 about here

---

4. Discussion

We examined the role of dynamic structures, movement amplitude, and their combination for anticipation. We expected that anticipation of tennis shot direction would be made possible when simulations contained dynamic differences in shot direction (Huys et al., 2008), be it in the presence or absence of movement amplitude differences in shots to different directions. Furthermore, we expected that their combined effect may further facilitate anticipation performance, potentially in a skill-dependent manner. In support of these predictions, both the D^PA^P and the D^PA^A conditions were anticipated significantly more accurately than the D^AA^P condition. In other words, dynamic structures did allow for anticipation of shot direction. However, shot-direction specific differences in movement amplitude (as reported by Huys et al., 2008) did not allow for nor facilitate anticipation of shot direction on its own nor in combination with the dynamical differences. This result was also reflected in the intermediate skill tennis players anticipation accuracy compared to chance level: Their accuracy was above chance level in the D^PA^P and D^PA^A conditions but not in the D^AA^P condition, showing that the dynamic structures informed the intermediate skill group about the shot direction to be anticipated. In addition, above chance level performance of the low-skill group was only found in the D^PA^A condition, suggesting that these players were hindered in extracting the necessary information when the dynamical differences in shot direction and movement amplitude were combined. Whilst we do not have any response time data to rule out a potential skill-dependent speed-accuracy trade off, taken together, these findings show that visual perception of dynamic structures is important for successful anticipation.

Shot-direction movement amplitude, at least as it was isolated here, did not facilitate anticipation of shot direction in either skill group, despite the existence of statistical differences in movement amplitudes between shot directions (Huys et al.,

2008). These differences in shot direction movement amplitude, while statistically reliable, may not be perceptually "meaningful" for anticipating shot direction, however, or be too small to be perceived by the skill groups used in this study. In that regard, one could speculate that the improved recognition of the flat service when exaggerating the styles as reported in Pollick et al. (2001) occurred because the exaggeration facilitated perceiving the style's (low-dimensional) dynamics. This facilitation may occur for styles that require the ball to be struck such that a large amount of spin results from the ball-racket contact (i.e., the slice or topspin styles). Alternatively, amplitude differences may be "ignored" over an informational quantity that is (more) reliable for determining tennis shot direction (i.e., low-dimensional dynamic structures). The low-dimensional dynamic structures appear to be a reliable informational quantity when anticipating shot direction from whole-body movements, in our view precisely so as they contain the deterministic component(s) that underlies the unfolding event, which is not the case for amplitude (but below). Low-dimensional dynamical structures in high-dimensional motion patterns are isolated by determining the greatest degree of similarity between joint trajectories across and between individuals. Therefore, because these structures capture most of the entire variance, co-varying patterns of movement within these trajectories across players and trials are captured. Thus, reliable visual perception of that movement is made possible by visual perception of these structures (cf. Huys et al., 2008, 2009). It is by this process of perceiving dynamic structures that the tennis player could be provided with information for anticipating general outcomes of whole-body movements. Additionally, movement amplitude for anticipation may well be of limited value because it likely reflects, at least to some extent, the unique anthropomorphic and possibly style characteristics of a player. For example, in this experiment the player-

specific standard deviations were used to reconstruct the particular player movement excursions. As a result, a generalizable informal quantity to determine shot direction may not be perceived from movement amplitude. In that regard, amplitude, as isolated here, is not a time varying quantity. However, movement amplitude in tennis may provide information about other future ball flight characteristics, such as ball speed. In line with this suggestion is the finding that, while present, dynamical differences are less present in shots of different depths than in shots to different directions (Huys et al., 2008). Shot depth is arguably primarily varied by adjusting the impulse provided to the ball, and it is thus well conceivable that the motion amplitudes facilitate the anticipation of shots with different depths.

The low-skill tennis players were only able to exploit shot direction differences in the dynamics when shot direction movement amplitude differences were removed. When both differences in movement amplitude and dynamic structures were combined performance in this group was no better than chance, whereas presentation of differences in dynamic structures alone resulted in above chance performance. The enhanced performance in the absence of movement amplitude not only demonstrates that shot direction differences in the dynamic structures are readily perceivable (regardless their scaling) even without a great deal of experience or skill in that domain, but furthermore suggests that the addition of non-dynamic differences between shots may deteriorate the performance of novices. Presumably skilled players have learnt to discriminate shot direction invariance in the dynamic structures from variant motion across players and trials. If this is the case an intriguing question follows. If discrimination of shot direction invariance in the dynamic structures from variant motion is what is learned during perceptual training, then to what extent is variant motion across players and trials within the training stimuli necessary? Given

the proposed importance of learning to discriminate shot direction invariance in dynamic structures from variable motion in skilful anticipation (*cf.* Huys et al., 2008), those wishing to acquire anticipation skill may benefit from exposure to the latter next to the invariance (i.e., low-dimensional dynamic structures) during practice. Thus, discrimination could be facilitated by learners having this environmental constraint imposed upon them. A learning study addressing this issue would provide concrete evidence on this practical and theoretical implication.

As hinted at above, movement amplitude differences may impair anticipation of shot direction in low-skill tennis players. This finding may help to understand how deceptive actions can mislead individuals with a low level of skill whilst individuals with a higher level of skill are unaffected. In the context of rugby, Jackson Warren, and Abernethy (2006) aimed to intentionally deceive participants tasked with anticipating the direction a player would run past them by asking the rugby players to exaggerate a particular movement. Deception was thought to be achieved by exaggerating counter-predictive cues in the players' movement. They found that when viewing deceptive movements, anticipation accuracy was reduced in comparison to the non-deceptive action, but only in less skilled and not in skilled rugby players (also see Cañal-Bruland & Schmidt, 2009; Sebanz & Shiffrar, 2009, for the recognition of deceptive movements). Presumably, the skilled players' anticipation performances were enabled by the perception of the low-dimensional dynamical structures across deceptive and non-deceptive actions while less skilled players were led astray by the exaggerated movement which may reflect perception of movement amplitude in these actions. Providing partial support of this hypothesis, Williams, Huys, Cañal-Bruland, and Hagenmann (2009) found that when the dynamics were (solely) locally manipulated to present conflicting shot direction information alongside the "normal"

dynamics corresponding to the remaining motion patterns of a tennis player, the perceptually skilled tennis players' anticipation accuracy was almost always impaired by this manipulation. Further evaluation of this hypothesis can be explicitly tested for in future research by identifying how dynamic structures and movement amplitude are modified in deceptive movements and investigating their informational value.

In conclusion, the findings from the current study concur with those of Huys et al. (2008) in supporting the prediction that kinematic information for anticipating tennis shot direction is carried in the dynamic structures identifiable though PCA. Taking these results together, skilled anticipation appears to be underpinned by the ability to identify low-dimensional dynamic structures from high-dimensional kinematic patterns and differences between shot directions contained in movement amplitude do not enhance this ability.

References

Abernethy, B., Gill, D. P., Parks, S. L., & Packer, S. T. (2001). Expertise and the perception of kinematic and situational probability information. *Perception*, *30*, 233-252.

Atkinson, A. P., Dittrich, W. H., Gemmell, A. J., & Young, A. W. (2004). Emotion perception from dynamic and static body expressions in point-light and full-light displays. *Perception*, *104,* 717-746.

Balk, S. A., Tyrrell, R. A, Brooks, J., & Carpenter, T. L. (2008). Highlighting human form and motion information enhances the conspicuity of pedestrians at night. *Perception*, *37,* 1276-1284.

Blake, R., & Shiffrar, M. (2006). Perception of human motion. *Annual Review of Psychology, 58,* 47-73.

Bruce, V., Green, P. R., Georgeson, M. A. (2004). *Visual perception: Physiology, psychology and ecology* (4th edition). Hove: Psychology Press.

Cañal-Bruland, R., & Schmidt, M. (2009). Response bias in judging deceptive movements. *Acta Psychologica, 130,* 235-240.

Daffertshofer, A., Lamoth, C. J., Meijer, O. G., & Beek, P. J. (2005). PCA in studying coordination and variability: A tutorial. *Clinical Biomechanics*, *19*, 415-428.

Haken, H. (1996). *Principles of brain functioning. A synergetic approach to brain activity.* Berlin: Springer.

Haken, H. (2000). *Information and self-organization*. *A macroscopic approach to complex systems*. Berlin: Springer.

Haken, H. (2004). *Synergetic computers and cognition: A top-down approach to neural nets*. New York, Springer.

Huys, R., Canal-Bruland, R., Hagemann, N., Beek, P. J., Smeeton, N. J., & Williams, A. M. (2009). Global information pickup underpins anticipation of tennis shot direction. *Journal of Motor Behavior, 41,* 158-170.

Huys, R., Smeeton, N. J., Hodges, N. J., Beek, P. J., & Williams, A. M. (2008). On the dynamical information underlying visual anticipation skill in perceiving tennis shots. *Perception & Psychophysics, 70,* 1217–1234.

Huys, R., Studenka, B. E., Rheaume, N. L., Zelaznik, H. N., & Jirsa, V. K. (2008). Distinct timing mechanisms produce discrete and continuous movements. *PLoS Computational Biology, 4*: e1000061

Jackson, R. C., Warren, S., & Abernethy, B. (2006). Anticipation skill and susceptibility to deceptive movement. *Acta Psychologica, 123,* 355-371.

Jirsa, V. K., & Kelso, J. A. S. (2005). The excitator as a minimal model for the coordination dynamics of discrete and rhythmic movement generation. *Journal of Motor Behavior, 37*, 35-51.

Johansson, G. (1976). Spatio-temporal differentiation and integration in visual motion perception. *Psychological Research*, *38*, 379-393.

Kelso, J. A. S. (1995). *Dynamic patterns: The self-organization of brain and behavior*. Cambridge, Mass.: MIT Press.

Mather, G. (2009). *Foundations of perception*. Hove: Psychology Press.

Milner, A. D., & Goodale, M. A. (1995). *The visual brain in action*. Oxford: Oxford University Press.

Muchisky, M. M., & Bingham, G. R. (2002). Trajectory forms as a source of information about events. *Perception & Psychophysics, 64*, 15-31.

Perdikis, D., & Jirsa, V. K. (2010) Recognition of behavioral patterns. *XII Congreso Nacional de Psicologia de la Actividad Fisica y el Deporte*, *14,* 48.

Pollick, F. E., Fidopiastis, C., & Braden, V. (2001). Recognizing the style of spatially exaggerated tennis serves. *Perception*, *30*, 323-338.

Runeson, S., & Frykholm, G. (1983). Kinematic specification of dynamics as an informational basis for person-and-action perception: Expectation, gender recognition, and deceptive intention. *Journal of Experimental Psychology: General*, *112*, 585-615.

Shim, J., Carlton, L. G., Chow, J. W., & Chae, W. S. (2005). The use of anticipatory visual cues by highly skilled tennis players. *Journal of Motor Behavior*, *37*, 174-175.

Sebanz, N., & Shiffrar, M. (2009). Bluffing bodies: Inferring intentions from actions. *Psychonomic Bulletin & Review, 16,* 170-175.

Strogatz, S. H. (1994) *Nonlinear dynamics and chaos. With applications to physics, biology, chemistry, and engineering*. Cambridge, Mass.: Perseus.

Troje, N. F. (2002). Decomposing biological motion: A framework for analysis and synthesis of human gait patterns. *Journal of Vision*, *2*, 371-387.

van der Kamp, J., Rivas, F., van Doorn, H., & Savelsbergh, G. (2008). Ventral and dorsal contributions to visual anticipation of fast ball sports. *International Journal of Sports Psychology, 39,* 100-130.

Ward, P., Williams, A. M., & Bennett, S. J. (2002). Visual search and biological motion perception in tennis. *Research Quarterly for Exercise and Sport, 73*, 1, 107-112.

Westhoff, C., & Troje, N. F. (2007). Kinematic cues for person identification from biological motion. *Perception & Psychophysics, 69*, 241-253.

Williams, A. M., Huys, R., Cañal-Bruland, R., & Hagemann, N. (2009). The dynamical information underpinning anticipation skill. *Human Movement Science*, *28,* 362-370.

Wilson, A., & Bingham, G. P. (2001). Dynamics, not kinematics, is an adequate basis for perception. *Behavioral and Brain Sciences, 24*, 4, 709-710.

Zar, J. H. (1996). *Biostatistical analysis* (3rd edition). Prentice Hall, Upper Saddle River, New Jersey, USA.

Figure Captions

Fig. 1. Shot Prediction Accuracy (%) of all participants in the D^PA^P, D^PA^A, and D^AA^P conditions. The error bars indicate the standard deviations

Fig. 2. Shot Prediction Accuracy (%) of Intermediate Skill and Low Skill Groups in the D^PA^P, D^PA^A,, and D^AA^P conditions. The error bars indicate standard deviations. Dashed line indicates chance level performance and the asterisks indicate performance accuracy that is statistically difference from chance level.

Footnotes

1. In addition, several interaction effects were found, and similarly so for the comparison between "deep" shots compared to "short" shots (see Huys et al., 2008 for details). However, the details of these effects are not relevant for our present purposes and will therefore not be discussed here.

2. Some authors (e.g., van der Kamp, Rivas, van Doorn, & Savelsbergh, 2008) have argued that perceptual results obtained in video-based tasks cannot be extrapolated to their analogue tasks involving the motor act used *in situ* because the former would rely in the vision-for-perception stream, whereas the latter would rely on the vision-for-action stream (*cf.* Milner & Goodale, 1995). However, these visual streams are unlikely to act in isolation (cf. Wilson & Bingham, 2001) and several authors have pointed out that there may be considerable "crosstalk" between the two streams (e.g., Bruce, Green, & Georgeson, 2004; Mather, 2006;). We therefore believe that for the present purposes the task used is appropriate.